Caving Cu-Au Porphyry

Prepared by Jarek Jakubec
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Cave Mining Cu-Au Porphyry

There are over 45 cave mining projects in various stages of studies and development around the world. Cave mining methods will be the underground method of choice in the future. It is only relatively recent that this mass mining method, despite 70 years of use, has begun proving its potential.

That interest is being fueled by the depletion of near surface ore bodies suitable for open pit operations. Many mining companies are turning to cave mining when they need to transition their operations from open pit to underground or if they need to exploit large low-grade resources at depth which would not support a more expensive mining method. Cave mining methods are becoming more popular due to relatively higher metal prices, projected supply and demand forecasts, and a lower discovery rate of significant new surface deposits. Cave mining is the primary underground mining method for extracting large Cu-Au porphyry deposits and this talk will highlight some of the recent development and challenges.

Jarek Jakubec, SRK Corporate Consultant, has over 30 years of operating and consulting experience in Mining, Geology and Rock Mechanics and his focus is on mass mining. Jarek has been involved in various capacities in most of the cave mines and cave mining projects around the world. He participated on several research programs, published numerous papers and most currently in collaboration with Infomine and UBC introduced web based Cave Mining Forum.
Agenda

Cave Mining
Caving Mines of the World
Cu-Au Porphyry Cave Mines
Cave Mining Challenges
WHY CAVING?

• High production rates:
  - Today’s mines 30 - 60 ktpd
  - Today’s projects > 120-140 ktpd

• Lowest mining costs per ton compared to any underground mining method - $4-7/t

• Suitable for automation – ore factory concept

• Small damage footprint compared to open pit methods
Environmental Impact

- **Open Pit and Dumps Footprint**: Approximately 6,000 ha
- **Cave Subsidence Footprint**: Approximately 600 ha
- **Orebody Footprint**: Approximately 60 ha/level
- **Open Pit Footprint**: Approximately 600 ha
Cave Mining Concept

(a) Initial Caving (point 1)

(b) Cave propagation toward surface (point 2)

(c) Initial surface subsidence as the crown thins (points 3-4)

(d) Cave breaches surface and forms a crater (points 5-6)
Cave Mines and Projects

Physical Map of the World, August 1999

PAST PRODUCERS

PRODUCERS

PROJECTS

JAKUBEC 2012

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Cave Mines – Current and Past Producers
Cave Mines – Current Producers
## Cave Mines – Cu Au Porphyry

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<thead>
<tr>
<th>Country</th>
<th>Name</th>
<th>Project</th>
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Cave Mines – Cu Au Porphyry

Physical Map of the World, August 1999

- Past Producers
- Producers
- Projects
- Non Porphyry Caves

JAKUBEK 2012
Cave Mines - Footprints

Northparkes E26/1 Area: < 5 ha

Palabora Area: 12 ha

Nuevo Nivel Mina, Teniente Area: 250 ha

Chuquicamata Area: 63 ha per level, 247 ha total

Grasberg Area: 70 ha
Cave Mines and Projects

No precedent in cave mining

After E. T. Brown 2005
COMMENTS ON DESIGN PROCESS
# Cave Mines – Design Criteria

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<th>Geological Logging</th>
<th>Lithological Unit Definition (Material Zones)</th>
<th>Cavability Analysis</th>
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<td>Rock Mass Properties (MRMR, Densities, DRMs)</td>
<td>Stability Analysis</td>
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<td>Point Load Testing</td>
<td>Structural Properties (Roughness, Orientation, Frequencies)</td>
<td>Undercut Strategy</td>
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<td>Density Measurement</td>
<td>Hydrological Properties (Aquifer Distribution)</td>
<td>Fragmentation Analysis</td>
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<td>Down Hole Survey</td>
<td>Material Properties (Intact Rock Strength, Joint Strength, Densities)</td>
<td>Subsidence Analysis</td>
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<td>Core Orientation</td>
<td>Stress Characterization (Magnitude and Orientation)</td>
<td>Mud Flow Risk Assessment</td>
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<td>Joint Measurement</td>
<td>Laboratory Testing</td>
<td>Production Rates/Equipment</td>
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<td>Aquifer Definition</td>
<td>Weathering Assessment</td>
<td>Production Layout/Support</td>
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Caveability
CAVE MINING REQUIRES THAT ROCK FRAGMENTS ITSELF INTO SUITABLE BLOCK SIZES WITHOUT BLASTING.

FRAGMENTATION MUST BE KNOWN BEFOREHAND AS IT INFLUENCES:

- DRAWPOINT SPACING
- AMOUNT OF SECONDARY BLASTING
- HANGUPS AND DELAYS
- PRODUCTION RATES AND DRAW CONTROL
- DRAWPOINT AND DRAWBELL SIZE
- EQUIPMENT SIZE AND TYPE
- RAMP UP PERIOD
Subsidence

NOTE: All Angles are measured from the Extraction Level

C = Cave Angle = Angle of Break
E = Angle of Draw = (90 – C)
A = Fracture Initiation Angle
B = Angle of Subsidence
The risk of poor subsidence estimates is typically related to infrastructure location outside the subsidence limits (below). In smaller footprints and strong rock masses the subsidence angles could be negative (overhang) resulting in ore loss and early dilution!
Active Open Pit Mining in Subsidence Zone
PRE-CONDITIONING, SUPERCAVES AND VERY HIGH LIFTS
SUPERCAVES PROJECTS (production rates over 100 ktpd)

- EL TENIENTE NEW MINING LEVELS
- GRASBERG COMPLEX
- CHUQUICAMATA
- OYU TOLGOI
- RESOLUTION
- BINGHAM CANYON
- PEBBLE

The question is how many will materialize!
Supercaves

Project reserves 1.656 Mt @ 0.71% Cu – for 90 years!
Supercaves

TODAY’S PROJECTS BUT HOW MANY MINES?

CADIA EAST

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Transform a highly competent rock mass (primary rock) into a rock mass material appropriate for caving methods.
Preconditioning

Transform a highly competent rock mass (primary rock) into a rock mass material appropriate for caving methods.
WHAT CAN GO WRONG?
Technical Challenges

ACCESS DEVELOPMENT

- STRESS, WATER, GROUND CONDITIONS, STRESS (UNDERGROUND EXPOSURE PRIOR TO COMPLETION OF FS)
- POOR GROUND SUPPORT DESIGN AND/OR INSTALLATION (QA/QC)

CAVE DEVELOPMENT

- UNDERCUTTING STRATEGY
- CAVEABILITY PREDICTIONS
- GROUND SUPPORT AND DEVELOPMENT RATES
- ABUTMENT STRESS DAMAGE
- SEISMICITY
Technical Challenges

RAMP UP
- DRAW RATE PREDICTIONS
- FRAGMENTATION PREDICTIONS
- AIR BLAST AND ROCKBURSTS
- LARGE SCALE WEDGE LOADING

PRODUCTION
- FINES INGRESS, MUDRUSHES AND WATER INFLOW
- BROW WEAR AND STABILITY
- SECONDARY BLAST DAMAGE
- COMPACTION AND STABILITY
- SUBSIDENCE & WEDGE LOADING
- DILUTION
Cave mining is one of the safest underground mining method. Once the cave is commissioned, personnel is not exposed to unsupported ground, blasting etc. During the development of the cave the main risks are:

- **AIRBLASTS**
- **SEISMIC BURSTS AND COLLAPSES**

During the production the main risk is:

- **MUDRUSH AND FINES INGRESS**
Stability

STABILITY OF THE CAVE MINING LEVELS (UNDERCUT, PRODUCTION AND MATERIAL/VENTILATION) IS AS IMPORTANT AS DRAWPOINT INTERACTION

STABILITY IS IMPACTED PRINCIPALLY BY THE FOLLOWING ACTIVITIES:

- UNDERCUTTING STRATEGY – ABUTMENT STRESS
- GROUND SUPPORT DESIGN AND QUALITY INSTALLATION
- DRAW STRATEGY
Stability

Typical rockburst damage, UCL drift, Ten sub 6 El Teniente (1991)
Stability

Poor ground support

Poor stress management
Mudrush

One of the potential hazards that should be evaluated during early stages of the mining study is that of a mudrush.

Several terms have been used in the industry to describe the sudden ingress of wet material into underground workings. The most common are mudrush, mudflow, mudpush, and wet muck.

All of them describe the phenomenon, which can have very different origins but produce the same result: injury, loss of life, damage to property, excess dilution, production delays or closure of a mine.
Mudrush

Highly mobile mudrush in Cullinan Mine (left) and stiff clays at E26 Northparkes
Cave Mines - Challenges
THANK YOU FOR YOUR ATTENTION!